Appendix H
Evaluation of Human Health Effects from Normal Facility Operations

H.1 INTRODUCTION

This appendix presents detailed information on the methodology employed for calculating potential impacts and risks to humans associated with releases of radioactivity and hazardous chemicals from the proposed facilities during normal operations and certain accident scenarios. This information is intended to support the public and occupational health and safety assessments described in Chapter 4 of this *Draft Programmatic Environmental Impact Statement for Accomplishing Expanded Civilian Nuclear Energy Research and Development and Isotope Production Missions in the United States, Including the Role of the Fast Flux Test Facility* (*Nuclear Infrastructure Programmatic Environmental Impact Statement* [NI PEIS]). Section H.2.1 provides general background information on ionizing radiation and associated health effects, Section H.2.2 discusses the methodology used in the assessment of normal radiological impacts, and Section H.2.3 provides a brief overview of data used in the radiological assessments. Hazardous chemical impacts are presented in Section H.3. Further detailed information regarding potential radiological impacts resulting from facility accidents are discussed in Appendix I of this NI PEIS.

This appendix presents numerical information using engineering and/or scientific notation. For example, the number 100,000 can also be expressed as 1×10^{5}. The fraction 0.00001 can also be expressed as 1×10^{-5}. The following chart defines the equivalent numerical notations that may be used in this appendix.

Fractions and Multiples of Units

Multiple	Decimal Equivalent	Prefix	Symbol
1×10^{6}	1,000,000	mega-	M
1×10^{3}	1,000	kilo-	k
1×10^{2}	100	hecto-	h
1×10	10	deka-	da
1×10^{-1}	0.1	deci-	d
1×10^{-2}	0.01	centi-	c
1×10^{-3}	0.001	milli-	m
1×10^{-6}	0.000001	micro-	μ
1×10^{-9}	0.000000001	nano-	n
1×10^{-12}	0.000000000001	pico-	p
1×10^{-15}	0.000000000000001	femto-	f
1×10^{-18}	0.000000000000000001	atto-	a

H.2 RADIOLOGICAL IMPACTS ON HUMAN HEALTH

H.2.1 Background Information

H.2.1.1 Nature of Ionizing Radiation and Its Effects on Humans

What Is Ionizing Radiation? Ionizing radiation (hereafter referred to as "radiation") is energy transferred in the form of particles or waves. Humans are exposed constantly to cosmic radiation and radiation from the earth's rocks and soil. (The term "radiation" encompasses several phenomena, including light, heat waves,

microwaves, radio waves, and ionizing radiation. The discussion of radiation in this section addresses ionizing radiation, and the term "radiation" is used to mean ionizing radiation.) This radiation contributes to the natural background radiation that has always surrounded us. Manmade sources of radiation also exist, including medical and dental x-rays, household smoke detectors, and materials released from nuclear and coal-fired powerplants.

Radiation comes from the activity of atoms, which form the substance of all matter in the universe. Atoms are composed of even smaller particles (protons, neutrons, electrons), whose number and arrangement distinguish atoms of one element from another. Elements consist of atoms having the same number of protons. Atoms of the same element with varying numbers of neutrons are known as isotopes of that element. There are more than 100 natural and manmade elements. Some of these isotopes (including isotopes of elements, such as uranium, radium, plutonium, and thorium) share a very important quality: they are unstable (i.e., they decay). As they change into more stable forms, invisible waves of energy or particles, known as ionizing radiation, are released. Radioactivity is the emitting of this radiation.

Ionizing radiation refers to the fact that this energy emitted from unstable atoms can ionize, or electrically charge, atoms by stripping off electrons, leaving them with a positive charge. Ionizing radiation can cause a change in the chemical composition of many materials, including living tissue (organs), which can affect the way they function.

- Alpha particles are one type of ionizing radiation and the heaviest of the types discussed here; despite a speed of approximately 16,000 kilometers per second (9,940 miles per second), they can travel only several centimeters in air. Alpha particles lose their energy almost as soon as they collide with anything. They can be stopped easily by a sheet of paper or by the skin's surface.

Radiation Type	Typical Speed (km/sec)	Typical Travel Distance in Air (meters)	Barrier
Alpha	16,000	Less than 1	Sheet of paper or skin's surface
Beta	160,000	3	Thin sheet of aluminum foil or glass
Gamma	300,000	Very large[a]	Thick wall of concrete, lead, or steel
Neutron	39,000	Very large	Water, paraffin, graphite

a. Would be infinite in a vacuum.

- Beta particles are much lighter than alpha particles. They can travel at a speed of up to 160,000 kilometers per second (99,400 miles per second) and can travel in the air for a distance of approximately 3 meters (9.8 feet). Beta particles can pass through a sheet of paper but may be stopped by a thin sheet of aluminum foil or glass.

- Gamma rays and x-rays, unlike alpha or beta particles, are waves of pure energy. Gamma rays travel at the speed of light (300,000 kilometers per second [186,000 miles per second]). Gamma radiation is very penetrating and requires a thick wall of concrete, lead, or steel to stop it.

- The neutron is another particle that contributes to radiation exposure, both directly and indirectly. The latter is associated with the gamma rays and alpha particles that are emitted following neutron capture in matter. A neutron has about one quarter the weight of an alpha particle and can travel at speeds of up to 39,000 kilometers per second (24,200 miles per second). Neutrons are more penetrating than beta particles but typically less penetrating than gamma rays.

The effects on people of radiation emitted during the disintegration (decay) of a radioactive substance depend on the type of radiation (alpha and beta particles and gamma and x-rays) and the total amount of radiation energy absorbed by the body. The total energy absorbed per unit quantity of tissue is referred to as absorbed dose. The absorbed dose, when multiplied by certain quality factors and factors that take into account different sensitivities of various tissues, is referred to as effective dose equivalent or, where the context is clear, simply dose. The common unit of effective dose equivalent is the roentgen equivalent man (rem); 1 rem equals 1,000 millirem.

The radioactivity of a material decreases with time. The time it takes a material to lose half of its original radioactivity is designated its half-life. For example, a quantity of iodine-131, a material that has a half-life of eight days, will lose one-half of its radioactivity in that amount of time. In eight more days, one-half of the remaining radioactivity will be lost, and so on. Eventually, the radioactivity will essentially disappear. Each radioactive element has a characteristic half-life. The half-lives of various radioactive elements may vary from millionths of a second to millions of years.

When a radioactive element emits a particle or gamma-ray, it often changes to an entirely different element, one that may or may not be radioactive. Eventually, a stable element is formed. This transformation, which may take several steps, is known as a decay chain. Radium, for example, is a naturally occurring radioactive element with a half-life of 1,622 years. It emits an alpha particle and becomes radon, a radioactive gas with a half-life of only 3.8 days. Radon decays first to polonium, then through a series of steps to bismuth, and ultimately to lead.

Units of Radiation Measure. Scientists and engineers use a variety of units to measure radiation. These different units can be used to determine the amount, type, and intensity of radiation. Just as heat can be measured in terms of its intensity or effects using units of calories or degrees, amounts of radiation can be measured in curies, radiation absorbed dose (rad), or rem.

- **Curie.** The curie, named after the French scientists Marie and Pierre Curie, describes the "intensity" of a sample of radioactive material. The rate of decay of 1 gram of radium is the basis of this unit of measure. It is equal to 3.7×10^{10} disintegrations (decays) per second.

- **Rad.** The total energy absorbed per unit quantity of tissue is referred to as absorbed dose. The rad is the unit of measurement for the physical absorption of radiation. As sunlight heats pavement by giving up an amount of energy to it, radiation gives up rads of energy to objects in its path. One rad is equal to the amount of radiation that leads to the deposition of 0.01 joule of energy per kilogram of absorbing material.

Radiation Units and Conversions

1 Ci = 3.7×10^{10} sec^{-1} = 3.7×10^{10} becquerel
1 rad = 100 erg/g = 0.01 gray
1 erg = 10^{-7} joule
1 gray = 1 joule/kg = 100 rad
1 rem = 0.01 sievert

- **Rem.** A rem is a measurement of the dose from radiation based on its biological effects. The rem is used in measuring the effects of radiation on the body. Thus, 1 rem of one type of radiation is presumed to have the same biological effects as 1 rem of any other kind of radiation. This allows comparison of the biological effects of radionuclides that emit different types of radiation.

An individual may be exposed to ionizing radiation externally (from a radioactive source outside the body) or internally (from ingesting or inhaling radioactive material). The external dose is different from the internal dose because an external dose is delivered only during the actual time of exposure to the external radiation

source, but an internal dose continues to be delivered as long as the radioactive source is in the body. For the analyses conducted in this NI PEIS, the dose from internal exposure is calculated over 50 years following the initial exposure; both radioactive decay and elimination of the radionuclide by ordinary metabolic processes decrease the dose rate with the passage of time.

The three types of doses calculated in this NI PEIS are external dose, internal dose, and combined external and internal dose. Each type of dose is discussed separately in the following paragraphs.

- **External dose.** The external dose can result from several different pathways, all having in common the fact that the radiation causing the exposure is external to the body. In this NI PEIS, these pathways include exposure to a cloud of radiation passing over the receptor or standing on ground that is contaminated with radioactivity. The appropriate measure of dose is called the effective dose equivalent. If the receptor departs from the source of radiation exposure, the dose rate will be reduced. It is assumed that external exposure occurs uniformly during the year.

- **Internal dose.** The internal dose results from a radiation source entering the human body via any means, such as through ingestion of contaminated food or water or inhalation of contaminated air. In this NI PEIS, pathways for internal exposure include: (1) ingestion of crops contaminated by airborne radiation deposits, (2) ingestion of animal products from animals that ingested contaminated food, and (3) inhalation of contaminated air. In contrast to external exposure, once radioactive material enters the body, it remains there for a period of time that depends on the rate of radiological decay and biological elimination rates. The unit of measure for internal doses is the committed dose equivalent. It is the internal dose that each body organ receives from the ingestion and inhalation of radioactive material. In this analysis of health impacts from normal operations, the committed dose equivalent is calculated for an annual intake period. Normally, a 50-year dose-commitment period is used (i.e., the 1-year intake period plus 49 years). The dose rate increases during the 1 year intake. The dose rate after the first year intake declines slowly as the radioactivity in the body continues to produce a dose. The integral of the dose rate over the 50 years gives the committed dose equivalent.

The various organs of the body have different susceptibilities to harm from radiation. The quantity that takes these different susceptibilities into account to provide a broad indicator of the risk to the health of an individual from radiation is called the committed effective dose equivalent. It is obtained by multiplying the committed dose equivalent in each major organ or tissue by a weighting factor associated with the risk susceptibility of the tissue or organ, then summing the totals. It is possible for the committed dose equivalent to an organ to be larger than the committed effective dose equivalent if that organ has a small weighting factor. The concept of committed effective dose equivalent applies only to internal pathways.

- **Combined external and internal dose.** The sum of the committed effective dose equivalent from internal pathways and the effective dose equivalent from external pathways is called the "total effective dose equivalent." The U.S. Department of Energy (DOE), in DOE Order 5400.5, calls this quantity the "effective dose equivalent."

The units used in this NI PEIS for committed dose equivalent, effective dose equivalent, and committed effective dose equivalent to an individual are the rem and millirem (1/1000 of 1 rem). The corresponding unit for the collective dose to a population (the sum of the doses to members of the population, or the product of the number of exposed individuals and their average dose) is the person-rem.

Sources of Background Radiation. The average American receives a total of approximately 360 millirem per year from all sources of radiation, both natural and manmade. The sources of radiation can be divided into six different categories: (1) cosmic radiation, (2) external terrestrial radiation, (3) internal radiation,

(4) consumer products, (5) medical diagnosis and therapy, and (6) other sources (NCRP 1987). These categories are discussed in the following paragraphs:

- **Cosmic radiation.** Cosmic radiation is ionizing radiation resulting from energetic charged particles from space continuously hitting the earth's atmosphere. These particles, and the secondary particles and photons they create, are cosmic radiation. Because the atmosphere provides some shielding against cosmic radiation, the intensity of this radiation increases with altitude above sea level. The average dose to the people in the United States from this source is approximately 27 millirem per year.

- **External terrestrial radiation.** External terrestrial radiation is the radiation emitted from the radioactive materials in the earth's rocks and soils. The average dose from external terrestrial radiation is approximately 28 millirem per year.

- **Internal radiation.** Internal radiation results from the human body metabolizing natural radioactive material that has entered the body by inhalation or ingestion. Natural radionuclides in the body include isotopes of uranium, thorium, radium, radon, polonium, bismuth, potassium, rubidium, and carbon. The major contributor to the annual dose equivalent for internal radioactivity are the short-lived decay products of radon, which contribute approximately 200 millirem per year. The average dose from other internal radionuclides is approximately 39 millirem per year.

- **Consumer products.** Consumer products also contain sources of ionizing radiation. In some products such as smoke detectors and airport x-ray machines, the radiation source is essential to product operation. In other products, such as televisions and tobacco, the radiation occurs incidentally to the product function. The average dose from consumer products is approximately 10 millirem per year.

- **Medical diagnosis and therapy.** Radiation is an important diagnostic medical tool and cancer treatment. Diagnostic x-rays result in an average exposure of 39 millirem per year. Nuclear medical procedures result in an average exposure of 14 millirem per year.

- **Other sources.** There are a few additional sources of radiation that contribute minor doses to individuals in the United States. The dose from nuclear fuel-cycle facilities (e.g., uranium mines, mills, and fuel processing plants), nuclear power plants, and transportation routes has been estimated to be less than 1 millirem per year. Radioactive fallout from atmospheric atomic bomb tests, emissions of radioactive material from DOE facilities and facilities licensed by the U.S. Nuclear Regulatory Commission (NRC), emissions from certain mineral extraction facilities, and transportation of radioactive materials contribute less than 1 millirem per year to the average dose to an individual. Air travel contributes approximately 1 millirem per year to the average dose.

The collective (or population) dose to an exposed population is calculated by summing the estimated doses received by each member of the exposed population. This total dose received by the exposed population is measured in person-rem. For example, if 1,000 people each receive a dose of 1 millirem (0.001 rem), the collective dose is 1,000 persons × 0.001 rem = 1.0 person-rem. Alternatively, the same collective dose (1.0 person-rem) results if 500 people each receive a dose of 2 millirem (500 persons × 2 millirem = 1 person-rem).

Limits of Radiation Exposure. The amount of manmade radiation that the public may be exposed to is limited by Federal regulations. Although most scientists believe that radiation absorbed in small doses over several years is not harmful, U.S. Government regulations assume that the effects of all radiation exposures are cumulative.

Under the Clean Air Act, releases of materials to the atmosphere from DOE facilities is limited by the U.S. Environmental Protection Agency (EPA) to quantities that would produce a dose of less than 10 millirem per year to a member of the general public (40 CFR Part 61). DOE also limits to 10 millirem the dose annually received from material released to the atmosphere (DOE Order 5400.5). EPA and DOE also limit the annual dose to a member of the general public from radioactive releases in drinking water to 4 millirem, as required under the Safe Drinking Water Act (40 CFR Part 141, DOE Order 5400.5). The annual dose from all radiation sources from a nuclear-fuel-cycle facility site is limited by EPA to 25 millirem (40 CFR Part 190). The DOE annual limit of radiation dose from all pathways to a member of the general public is 100 millirem (DOE Order 5400.5).

Each of the three sites covered by this NI PEIS operates below all of these limits. The average individual in the United States receives a dose of approximately 0.3 rem (300 millirem) per year from natural sources of radiation. For perspective, a modern chest x-ray results in an approximate dose of 0.006 rem (6 millirem) and a diagnostic pelvis and hip x-ray results in an approximate dose of 0.065 rem (65 millirem) (NCRP 1987). An acute dose (i.e., a dose over a short period of time) of about 450 rem (450,000 millirem) would result in a 50 percent chance of death.

For people working in an occupation that involves radiation, NRC and DOE limit doses to 5 rem per year (5,000 millirem per year) (10 CFR Part 20, 10 CFR Part 835). The Administrative Control Level of 2 rem (2,000 millirem) per year is typically imposed at DOE sites to comply with "as low as is reasonably achievable" initiatives (10 CFR Part 835).

H.2.1.2 Health Effects

Radiation exposure and its consequences are topics of interest to the general public. For this reason, this NI PEIS places much emphasis on the consequences of exposure to radiation, even though the effects of radiation exposure under most circumstances evaluated in this NI PEIS are small. To provide the background for discussions of impacts, this section explains the basic concepts used in the evaluation of radiation effects.

Radiation can cause a variety of adverse health effects in people. The most significant adverse health effect that depicts the consequences of environmental and occupational radiation exposure is induction of cancer fatalities. This effect is referred to as "latent" cancer fatalities because the cancer may take many years to develop. In the discussions that follow, all fatal cancers are considered latent, and therefore the term "latent" is not used.

Health impacts from radiation exposure, whether from sources external or internal to the body, generally are identified as "somatic" (affecting the individual exposed) or "genetic" (affecting descendants of the exposed individual). Radiation is more likely to produce somatic effects than to produce genetic effects. For this NI PEIS, therefore, only the somatic risks are presented. The somatic risks of most importance are the induction of cancers. With the exception of leukemia, which can have an induction period (time between exposure to carcinogen and cancer diagnosis) of as little as 2 to 7 years, most cancers have an induction period of more than 20 years.

For a uniform irradiation of the body, the incidence of cancer varies among organs and tissues; the thyroid and skin demonstrate a greater sensitivity than other organs. Such cancers, however, also produce relatively low mortality rates because they are relatively amenable to medical treatment. Because of the readily available data for cancer mortality rates and the relative scarcity of prospective epidemiologic studies, somatic effects leading to cancer fatalities rather than cancer incidence are presented in this NI PEIS. The numbers of cancer fatalities can be used to compare the risks among the various alternatives.

The National Research Council's Committee on the Biological Effects of Ionizing Radiation (BEIR) has prepared a series of reports to advise the U.S. Government on the health consequences of radiation exposures. The latest of these reports, *Health Effects of Exposure to Low Levels of Ionizing Radiation BEIR V* (NAS 1990), provides the most current estimates for excess mortality from leukemia, and cancers other than leukemia, expected to result from exposure to ionizing radiation. This report updates the models and risk estimates provided in an earlier report of the Committee, *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation*. The BEIR V models were developed for application to the U.S. population.

BEIR V provides estimates that are consistently higher than those in its predecessor BEIR III. This increase is attributed to several factors, including the use of a linear dose response model for cancers other than leukemia, revised dosimetry for the Japanese atomic bomb survivors, and additional follow-up studies of the atomic bomb survivors and other cohorts. BEIR III employs constant relative and absolute risk models, with separate coefficients for each of several sex and age-at-exposure groups; BEIR V develops models in which the excess relative risk is expressed as a function of age at exposure, time after exposure, and sex for each of several cancer categories. The BEIR III models were based on the assumption that absolute risks are comparable between the atomic bomb survivors and the U.S. population; BEIR V models were based on the assumption that the relative risks are comparable. For a disease such as lung cancer, where baseline risks in the United States are much larger than those in Japan, the BEIR V approach leads to larger risk estimates than the BEIR III approach.

The models and risk coefficients in BEIR V were derived through analyses of relevant epidemiologic data that included the Japanese atomic bomb survivors, ankylosis spondylitis patients, Canadian and Massachusetts fluoroscopy patients (breast cancer), New York postpartum mastitis patients (breast cancer), Israel Tinea Capitis patients (thyroid cancer), and Rochester thymus patients (thyroid cancer). Models for leukemia, respiratory cancer, digestive cancer, and other cancers used only the atomic bomb survivor data, although results of analyses of the ankylosis spondylitis patients were considered. Atomic bomb survivor analyses were based on revised dosimetry with an assumed relative biological effectiveness[1] of 20 for neutrons and were restricted to doses less than 400 rads. Estimates of risks of fatal cancers other than leukemia were obtained by totaling the estimates for breast cancer, respiratory cancer, digestive cancer, and other cancers.

Risk Estimates for Doses Equal To or Greater Than 20 Rem (Accident Scenarios). BEIR V includes risk estimates for a single exposure to a high level of radiation to all people in a large population group. The estimates are given in terms of lifetime risks per 1.0×10^6 person-rem. Fatality estimates for leukemia, breast cancer, respiratory cancer, digestive cancer, and other cancers are given for both sexes and nine age-at-exposure groups. These estimates, based on the linear model, are summarized in **Table H–1**. The average risk estimate from all ages and both sexes is 885 excess latent cancer fatalities per million person-rem. This value has been conservatively rounded up to 1,000 excess latent cancer fatalities per million person-rem.

Although values for other health effects are not presented in this NI PEIS, the risk estimators for nonfatal cancers and for genetic disorders to future generations are estimated to be approximately 200 and 260 per million person-rem, respectively. These values are based on information presented in the *1990 Recommendations of the International Commission on Radiological Protection* (ICRP 1991) and are seen to be 20 percent and 26 percent, respectively, of the fatal cancer estimator. Thus, if the number of excess latent fatal cancers is projected to be "X," the number of excess genetic disorders would be 0.26 times "X."

[1] A relative biological effectiveness factor is essentially used to represent a given radiation type's (neutron, gamma, alpha, etc.) ability to transfer energy to a given biological receptor.

Table H–1 Lifetime Risks per Million Person-Rem for Individual Exposures Greater Than 20 Rem

Gender	Type of Fatal Cancer		
	Leukemia[a]	Cancers Other Than Leukemia	Total Cancers
Male	220	660	880
Female	160	730	890
Average	190	695	885[b]

a. These are the linear estimates, which are double the linear-quadratic estimates provided in BEIR V for leukemia at low doses and dose rates.
b. This value has been rounded up to 1,000 excess cancer fatalities per million person-rem.
Source: NAS 1990.

Risk Estimates for Doses Less Than 20 Rem (Normal Operational Scenarios). For doses lower than 20 rem, a linear-quadratic model provides a significantly better fit to the data for leukemia than a linear model, and leukemia risks were based on a linear-quadratic function, which reduces the effects by a factor of two over estimates that are obtained from a linear model. For other cancers, linear models were found to provide an adequate fit to the data and were used for extrapolation to low doses. The BEIR V Committee, however, recommended reducing these linear estimates by a factor between 2 and 10 for doses received at low dose rates. For this NI PEIS, a risk reduction factor of two was adopted for conservatism.

Based on the preceding discussion, the resulting risk estimator would be equal to half the value observed for high-dose situations or approximately 500 excess latent cancer fatalities per million person-rem (0.0005 excess cancer fatality per person-rem). This is the risk value used in this NI PEIS to calculate cancer fatalities to the general public during normal operations and also for accidents in which individual doses are less than 20 rem. For workers, a value of 400 excess latent cancer fatalities per million person-rem (0.0004 excess latent cancer fatality per person-rem) is used in this NI PEIS. This lower value reflects the absence of children (who are more radiosensitive than adults) in the workforce. Again, based on information provided in the *1990 Recommendations of the International Commission on Radiological Protection* (ICRP 1991), the health risk estimators for nonfatal cancer and genetic disorders among the public are 20 percent and 26 percent, respectively, of the fatal cancer risk estimator. For workers, the health risk estimators are both 20 percent of the fatal cancer risk estimator. For this NI PEIS, only fatal cancers are presented.

The risk estimates may be applied to calculate the effects of exposing a population to radiation. For example, in a population of 100,000 people exposed only to natural background radiation (0.3 rem per year), 15 latent cancer fatalities per year would result from this radiation (100,000 persons × 0.3 rem per year × 0.0005 latent cancer fatality per person-rem = 15 latent cancer fatalities per year).

Calculations of the number of excess cancer fatalities associated with radiation exposure do not always yield whole numbers; calculations may yield numbers less than 1.0, especially in environmental applications. For example, if a population of 100,000 were exposed as described in the previous paragraph, but to a total dose of only 0.001 rem, the collective dose would be 100 person-rem, and the corresponding estimated number of latent cancer fatalities would be 0.05 (100,000 persons × 0.001 rem × 0.0005 latent cancer fatality per person-rem = 0.05 latent cancer fatality).

For latent cancer fatalities less than 1.0, the estimated 0.05 latent cancer fatality is a statistical estimate. The latent cancer fatality of 0.05 is the average number of deaths that would result if the same exposure situation were applied to many different groups of 100,000 people. In most groups, no person (zero people) would incur a latent cancer fatality from the 0.001 rem dose each member would have received. In a small fraction of the groups, one latent cancer fatality would result; in exceptionally few groups, two or more latent cancer fatalities

would occur. The average number of deaths over all the groups would be 0.05 latent cancer fatality (just as the average of 0, 0, 0, and 1 is 1/4, or 0.25). The most likely outcome is 0 latent cancer fatality.

These same concepts apply to estimating the effects of radiation exposure on a single individual. Consider the effects, for example, of exposure to background radiation over a lifetime. The "number of latent cancer fatalities" corresponding to a single individual's exposure over a (presumed) 72-year lifetime to 0.3 rem per year is the following:

1 person × 0.3 rem per year × 72 years × 0.0005 latent cancer fatality/person-rem = 0.011 latent cancer fatality.

Again, this is a statistical estimate; that is, the estimated effect of background radiation exposure on the exposed individual would produce a 1.1 percent chance that the individual might incur a latent cancer fatality caused by the exposure over his full lifetime. Presented another way, this method estimates that approximately 1.1 percent of the population might die of cancers induced by background radiation.

H.2.2 Methodology for Estimating Radiological Impacts

The potential radiological impacts associated with normal operating conditions and accidents at the processing facilities were calculated using Version 1.485 of the GENII computer code. Site-specific and technology-specific input data were used, including location, meteorology, population, food production and consumption, and source terms. Section H.2.2.1 briefly describes GENII and outlines the approach used for modeling normal operations and facility accidents.

H.2.2.1 GENII Computer Code

The GENII computer model, developed by DOE at the Pacific Northwest National Laboratory, is an integrated system of various computer modules that analyze environmental contamination resulting from acute or chronic releases to, or initial contamination in, air, water, or soil. The model calculates radiation doses to individuals and populations. The GENII computer model is well documented for assumptions, technical approach, methodology, and quality assurance issues (Napier et al. 1988). The GENII computer model has gone through extensive quality assurance and quality control steps, including comparing results from model computations with those from hand calculations and performing internal and external peer reviews. Recommendations given in these reports were incorporated into the final GENII computer model, as deemed appropriate.

For this NI PEIS, only the ENVIN, ENV, and DOSE computer modules were used. The codes are connected through data transfer files. The output of one code is stored in a file that can be used by the next code in the system.

- **ENVIN.** The ENVIN module of the GENII code controls the reading of input files and organizes the input for optimal use in the environmental transport and exposure module, ENV. The ENVIN code interprets the basic input, reads the basic GENII data libraries and other optional input files, and organizes the input into sequential segments based on radionuclide decay chains.

  A standardized file that contains scenario, control, and inventory parameters is used as input to ENVIN. Radionuclide inventories can be entered as functions of releases to air or water, concentrations in basic environmental media (air, soil, or water), or concentrations in foods. If certain atmospheric dispersion options have been selected, this module can generate tables of atmospheric dispersion parameters that will be used in later calculations. If the finite plume air submersion option is requested in addition to the atmospheric dispersion calculations, preliminary energy-dependent finite plume dose factors are prepared. The ENVIN module prepares the data transfer files that are used as

input by the ENV module; ENVIN generates the first portion of the calculation documentation—the run input parameters report.

- **ENV.** The ENV module calculates the environmental transfer, uptake, and human exposure to radionuclides that result from the chosen scenario for the user-specified source term. The code reads the input files from ENVIN and then, for each radionuclide chain, sequentially performs the precalculations to establish the conditions at the start of the exposure scenario. Environmental concentrations of radionuclides are established at the beginning of the scenario by assuming decay of preexisting sources, considering biotic transport of existing subsurface contamination, and defining soil contamination from continuing atmospheric or irrigation depositions. For each year of postulated exposure, the code then estimates the air, surface soil, deep soil, groundwater, and surface water concentrations of each radionuclide in the chain. Human exposures and intakes of each radionuclide are calculated for (1) pathways of external exposure from finite atmospheric plumes; (2) inhalation; (3) external exposure from contaminated soil, sediments, and water; (4) external exposure from special geometries; and (5) internal exposures from consumption of terrestrial foods, aquatic foods, drinking water, animal products, and inadvertent intake of soil. The intermediate information on annual media concentrations and intake rates are written to data transfer files. Although these may be accessed directly, they are usually used as input to the DOSE module of GENII.

- **DOSE.** The DOSE module reads the intake and exposure rates defined by the ENV module and converts the data to radiation dose.

H.2.2.2 Data and General Assumptions

To perform the dose assessments for this NI PEIS using the GENII code, different types of data were collected and/or generated. In addition, calculational assumptions were made. This section discusses both the data collected and/or generated for use in performing the dose assessments and the assumptions made for this NI PEIS.

- **Meteorological data.** The meteorological data used for all normal operational and accident assessments were in the form of Oak Ridge Reservation (ORR), Idaho National Environmental and Engineering Laboratory (INEEL), and Hanford Site (Hanford) joint frequency data files. A joint frequency data file is a table listing the fractions of time the wind blows in a certain direction, at a certain speed, and within a certain stability class. The joint frequency data files were based on measurements taken over a period of several years at different locations and heights. Average annual meteorological conditions (averaged over the measurement period) were used for normal operation and the 50th percentile atmospheric conditions were used for accident scenarios. (Accident analysis results and additional analysis detail are presented in Appendix I.)

- **Population data.** Population distributions were based on the *1990 Census of Population and Housing* data (DOC 1992). Projections were determined for the year 2020 (approximate midlife of operations) for areas within 80 kilometers (50 miles) of ORR, INEEL, and Hanford release locations. The site populations in 2020, assumed to be representative of the populations over the operational period evaluated, were used in the impact assessments. The populations were spatially distributed on circular grids with 16 directions and 10 radial distances up to 80 kilometers (50 miles). The grids were centered at the precise locations from which the radionuclides were assumed to be released.

- **Source term data.** Source term(s) (i.e., quantities of radioactive material released to the environment over a given period) were estimated based on characteristic releases associated with historical data. The source term used to estimate the incremental impacts of normal operations is 1.7×10^{-7} curies of

plutonium-238 per year (Wham 1999). Release quantities associated with processing facility accidents are provided in Appendix E.

- **Food production and consumption data.** Agricultural data from *Health Risk Data for Storage and Disposition of Weapons-Usable Fissile Materials Final Programmatic Environmental Impact Statement* (HNUS 1996) were used as a source for food production quantities. Food production was spatially distributed on the same circular grid used for the population distributions. The consumption rates used in GENII were those for the maximum individual and average individual. People living within the 80-kilometer (50-mile) assessment area were assumed to consume only food grown in that area.

- **Calculational assumptions.** For normal operations, impact assessments were performed for both members of the general public and workers associated with processing facility activities. These assessments were made to determine the incremental impacts that would be associated with the action alternatives addressed in this NI PEIS. Incremental doses for members of the public were calculated (via GENII) for two different types of receptors: the maximally exposed offsite individual and the general population living within 80 kilometers (50 miles) of a given facility. The maximally exposed individual associated with the alternatives addressed in this NI PEIS was assumed to be located at a position on the site boundary that would yield the highest impacts during normal operations of a given alternative. For facility workers, incremental doses were cited directly from facility-specific data reports. For doses associated with storage actions (i.e., "No Action" neptunium-237 storage), it was conservatively assumed that 10 percent of the total fabrication and processing doses are attributable to storage impacts exclusively.

To estimate radiological impacts from normal operations, the following additional assumptions and factors were considered in using GENII.

- Ground surfaces were assumed to have no previous deposition of radionuclides.

- The annual external exposure time to the plume and to soil contamination was 0.7 year (16.8 hours per day) for the maximally exposed offsite individual (NRC 1977).

- The annual external exposure time to the plume and to soil contamination was 0.5 year (12 hours per day) for the population (NRC 1977).

- The annual inhalation exposure time to the plume was 1.0 year for the maximally exposed individual and general population (NRC 1977).

- The exposed individual or population was assumed to have the characteristics and habits (e.g., inhalation and ingestion rates) of the adult human.

- A semi-infinite/finite plume model was used for air immersion doses. Other pathways evaluated were ground exposure, inhalation, ingestion of food crops and animal products contaminated by either deposition of radioactivity from the air or irrigation. No liquid pathways were analyzed because expected releases will only be to the air.

- Reported release heights were used for atmospheric releases and were assumed to be the effective stack heights.

- The calculated doses were 50-year committed doses from 1 year of intake.

The exposure, uptake, and usage parameters used in the GENII model for normal operations are provided in **Tables H–2** through **H–4**.

Table H–2 GENII Exposure Parameters to Plumes and Soil Contamination (Normal Operations)

Maximum Individual				General Population			
External Exposure		Inhalation of Plume		External Exposure		Inhalation of Plume	
Plume (hours)	Soil Contamination (hours)	Exposure Time (hours)	Breathing Rate (cm^3/sec)	Plume (hours)	Soil Contamination (hours)	Exposure Time (hours)	Breathing Rate (cm^3/sec)
6,136	6,136	8,766	270	4,383	4,383	8,766	270

Key: cm^3/sec, cubic centimeters per second.
Source: Napier et al. 1988; NRC 1977.

Table H–3 GENII Usage Parameters for Consumption of Terrestrial Food (Normal Operations)

	Maximum Individual				General Population			
Food Type	Growing Time (days)	Yield (kg/m^2)	Holdup Time (days)	Consumption Rate (kg/yr)	Growing Time (days)	Yield (kg/m^2)	Holdup Time (days)	Consumption Rate (kg/yr)
Leafy vegetables	90.0	1.5	1.0	30.0	90.0	1.5	14.0	15.0
Root vegetables	90.0	4.0	5.0	220.0	90.0	4.0	14.0	140.0
Fruit	90.0	2.0	5.0	330.0	90.0	2.0	14.0	64.0
Grains/cereals	90.0	0.8	180.0	80.0	90.0	0.8	180.0	72.0

Key: kg/m^2, kilograms per square meter; kg/yr, kilograms per year.
Source: Napier et al. 1988.

Table H–4 GENII Usage Parameters for Consumption of Animal Products (Normal Operations)

			Stored Feed				Fresh Forage			
Food Type	Consumption Rate (kg/yr)	Holdup Time (days)	Diet Fraction	Growing Time (days)	Yield (kg/m^2)	Storage Time (days)	Diet Fraction	Growing Time (days)	Yield (kg/m^2)	Storage Time (days)
Maximum individual										
Beef	80.0	15.0	0.25	90.0	0.80	180.0	0.75	45.0	2.00	100.0
Poultry	18.0	1.0	1.00	90.0	0.80	180.0	–	–	–	–
Milk	270.0	1.0	0.25	45.0	2.00	100.0	0.75	30.0	1.50	0.00
Eggs	30.0	1.0	1.00	90.0	0.80	180.0	–	–	–	–
General population										
Beef	70.0	34.0	0.25	90.0	0.80	180.0	0.75	45.0	2.00	100.0
Poultry	8.5	34.0	1.0	90.0	0.80	180.0	–	–	–	–
Milk	230.0	3.0	0.25	45.0	2.00	100.0	0.75	30.0	1.50	0.00
Eggs	20.0	18.0	1.0	90.0	0.80	180.0	–	–	–	–

Key: kg/m^2, kilograms per square meter; kg/yr, kilograms per year.
Source: Napier et al. 1988.

H.2.2.3 Health Effects Calculations

In this NI PEIS, the collective combined effective dose equivalent is the sum of the collective committed effective dose equivalent (internal dose) and the collective effective dose equivalent (external dose). Doses calculated by GENII were used to estimate health effects using the risk estimators presented in Section H.2.1.2. The incremental cancer fatalities in the general population and in groups of workers were, therefore, estimated by multiplying the collective combined effective dose equivalent by 0.0005 and 0.0004 cancer fatality per person-rem, respectively. Although health risk factors are statistical factors and not strictly applicable to individuals, they have been used in the past to estimate the incremental risk to an individual from exposure to radiation. Therefore, the factor of 0.0005 and 0.0004 per rem of individual committed effective dose equivalent for a member of the public and for a worker, respectively, have also been used in this NI PEIS to calculate the individual's incremental fatal cancer risk from exposure to radiation. As stated previously, for doses greater than 20 rem to an individual, these factors are doubled.

Under the realm of normal operations, for the public, the health effects expressed in this NI PEIS are the risk of fatal cancer to the maximally exposed individual and the number of fatal cancers to the 80-kilometer (50-mile) population from exposure to radioactivity released from any of the candidate sites over the full period of operations. For workers, the health effects expressed are the risk of fatal cancer to the average worker at a facility and the number of fatal cancers to all workers at that facility from the full period of operations.

H.2.2.4 Uncertainties

The sequence of analyses performed to generate the radiological impact estimates from normal operation include: (1) selection of normal operational modes, (2) estimation of source terms, (3) estimation of environmental transport and uptake of radionuclides, (4) calculation of radiation doses to exposed individuals, and (5) estimation of health effects. There are uncertainties associated with each of these steps. Uncertainties exist in the way the physical systems being analyzed are represented by the computational models and in the data required to exercise the models (due to measurement, sampling, or natural variability).

In principle, one can estimate the uncertainty associated with each source and predict the remaining uncertainty in the results of each set of calculations. Thus, one can propagate the uncertainties from one set of calculations to the next and estimate the uncertainty in the final results. However, conducting such a full-scale quantitative uncertainty analysis is neither practical nor a standard practice for a study of this type. Instead, the analysis is designed to ensure through judicious selection of release scenarios, models, and parameters, that the results represent the potential risks. This is accomplished by making conservative assumptions in the calculations at each step. The models, parameters, and release scenarios used in the calculations are selected in such a way that most intermediate results and, consequently, the final estimates of impacts are greater than what would be expected. As a result, even though the range of uncertainty in a quantity might be large, the value calculated for the quantity is close to one of the extremes in the range of possible values, so that the chance of the actual quantity being greater than the calculated value is low (or the chance of the quantity being less than the calculated value if the criteria are such that the quantity has to be maximized). This has been the goal of the radiological assessment for normal operation in this study (i.e., to produce results that are conservative).

The degree of conservatism in the calculated results is closely related to the range of possible values the quantity can have. This range is determined by what can be expected to realistically occur. Thus, the only processes considered are those credible for the conditions under which the physical system being modeled operates. This consideration has been employed for normal operation analyses.

Although the radionuclide composition of source terms are reasonable estimates, there are uncertainties in the radionuclide inventory and release reactions that affect estimated impacts.

H.2.3 Radiological Impact Assessment Data and Releases to the Environment

This section discusses the various site-dependent GENII input data required for quantifying the potential radiological impacts associated with the action alternatives in this NI PEIS. Agricultural data, population data, meteorological data, and release quantity data are discussed for the candidate sites.

- **Agricultural data.** Agricultural food production data (wheels) were cited from *Health Risk Data for Storage and Disposition of Weapons-Usable Fissile Materials Final PEIS* (HNUS 1996). The wheels were generated by combining the fraction of a county in each segment (e.g., south, southwest, north-northeast) and the county production of the eight food categories analyzed by GENII (leafy vegetables, root vegetables, fruits, grains, beef, poultry, milk, and eggs). Each county's food production (in kilograms) was assumed to be distributed uniformly over a given county's land area. These categorized food wheels were fed into GENII as an input file and were used in the assessment of doses to a given general population from the ingestion pathway.

- **Population data.** Population data (wheels) were generated based on the 1990 *U.S. Census of Population and Housing* (DOC 1992). For each block in the 1990 census, the population was assigned a distance and direction from the release point; then the block's population was projected based on estimates of county growth in the year 2020. The population in each segment (e.g., south, southwest, north-northeast) was cumulated over all the blocks in the census. These population wheels were fed into GENII as an input file and were used in the assessment of a total dose incurred to a given general population.

- **Meteorological data.** Meteorological data (i.e., joint frequency distributions) were based on measurements of the fractions (given as percentages) of time the wind blows in a certain direction, at a certain speed, and within a certain stability class for ORR, INEEL, and Hanford, as cited in *Health Risk Data for Storage and Disposition of Weapons-Usable Fissile Materials Final PEIS* (HNUS 1996). The joint frequency distribution data is derived from 1 year of data (from X–10 Plant Tower 4 at ORR [1990 data] and the Grid 3 meteorological tower [1986 data] at INEEL), 9 years of data (1983–1991 from Hanford's 400 Area tower), or 13 years of data (1983–1996 from Hanford's 300 Area Tower 11). Data for facilities to be located at a generic site (the new accelerator(s), research reactor, and support facility) are derived from the hourly meteorological data developed for the health impacts from facility accidents presented in Appendix I. These data were fed into GENII as an input file and were used in the evaluation of χ/Q or E/Q values (these values represent radioisotope concentrations divided by the rates at which they are emitted to the environment); these were then used to determine the total dose incurred to a given general population, or an offsite maximally exposed individual.

- **Radiological releases to the environment.** Normal operational radiological releases to the environment (1.7×10^{-7} curies per year plutonium-238) were determined based on the conservative assumption that a 5 kilograms (11 pounds) inventory of plutonium-238 is processed on an annual basis at ORR, INEEL, or Hanford. Employing a processing facility emission factor of 1.98×10^{-12} (Wham 1999), and a specific activity of 17 curies per gram, a resulting annual release quantity of 1.7×10^{-7} curies is calculated as shown below:

  (5,000 grams per year of plutonium-238) × (17 curies of plutonium-238 per gram of plutonium-238) × (1.98×10^{-12}) = 1.7×10^{-7} curies per year of plutonium-238

Normal operational releases associated with the fabrication and processing of medical target material are based on an estimate of the releases that might occur during the normal handling and processing of target materials,

including anticipated off-normal conditions such as powder spills. Ventilation systems in all facilities used for processing of the target material would consist of at least two sets of high-efficiency particulate air filters, providing an emission removal efficiency of 2.4×10^{-6} and a total facility emission factor of 1.5×10^{-9}. (The emission factor for the elements radon and krypton, both gases, is 1.0.) (BWHC 1999). This results in the normal operational releases shown in **Table H–5**. These are the normal operational releases used for the facilities that process only the medical targets; the source term for facilities that process both medical targets and the plutonium-238 would be a combination of the plutonium operational release defined above and the medical releases of Table H–5.

Table H–5 Annual Normal Operational Releases Associated with Medical Target Processing

Isotope	Quantity Released (curies per year)	Isotope	Quantity Released (curies per year)
Copper-64	4.9×10^{-5}	Xenon-131m	2.0×10^{1}
Zinc-65	5.2×10^{-6}	Europium-152	2.1×10^{-5}
Strontium-85	9.7×10^{-6}	Europium-152m	2.9×10^{-4}
Krypton-85	2.9×10^{-3}	Gadolinium-153	5.0×10^{-6}
Krypton-85m	4.5×10^{-4}	Samarium-153	1.4×10^{-4}
Molybdenum-99	6.3×10^{-5}	Europium-154	7.0×10^{-5}
Palladium-103	2.0×10^{-5}	Europium-155	1.6×10^{-5}
Rhodium-103m	2.0×10^{-5}	Europium-156	1.5×10^{-3}
Technetium-99m	6.9×10^{-5}	Holmium-166	2.2×10^{-6}
Cadmium-109	2.9×10^{-6}	Tungston-187	3.3×10^{-3}
Iodine-125	1.1×10^{-5}	Iridium-192	1.6×10^{-5}
Iodine-131	4.6×10^{-6}	Radon-222	4.3×10^{1}

Source: BWHC 1999.

The Radiochemical Processing Laboratory (RPL) at Hanford would require modification prior to its use in medical isotope target fabrication and processing. Preoperational activities were assumed to result in the same emissions as those associated with operation of the facility in 1998; modification activities are not expected to result in significant quantities of airborne particulate of gaseous materials in excess of those generated during facility operation in prior years (BWHC 1999). These normal operational emissions are provided in **Table H–6**.

Table H–6 Annual Normal Operational Releases from RPL During Preoperational Activities

Isotope	Quantity Released (curies per year)
Tritium	1.6×10^{2}
Strontium-90[a]	1.5×10^{-7}
Plutonium-239[a]	4.4×10^{-8}

a. Strontium and plutonium releases have been increased to include all alpha and beta emissions detected during facility operation but not attributed to any single isotope.

Source: BWHC 1999.

The normal operational releases associated with operation (for target irradiaion), preoperational startup, and standby operation of the Fast Flux Test Facility (FFTF) are based on measured releases for the facility in 1990 when the facility was operating at 300 megawatts and in 1998 when the facility was maintained in standby. These measured releases are provided in **Table H–7**. Normal operational releases have been scaled from those associated with 300-megawatt operations in 1990 to 400-megawatt operations. Operation at 400 megawatts was assumed for the analysis of normal operational impacts. Although operation at a lower power level should meet production goals for most of the mission time, operation at this higher level may be required and impacts

Table H–7 Annual Normal Operational Releases from FFTF

FFTF Normal Operations			
Isotope	**Quantity Released (curies per year)**		
	Combined Exhaust Release	**Heat Transport System Release**	**Service Building Release**
H-3 (tritium)	4.0	–	–
Argon-41	40	–	–
Cesium-137	6.4×10^{-7}	7.6×10^{-6}	7.6×10^{-6}
FFTF Standby			
Isotope	**Quantity Released (curies per year)**		
H-3 (tritium)	4.2		
Plutonium-239[a]	4.9×10^{-7}		
Strontium-90[a]	3.9×10^{-6}		

a. Plutonium and strontium are used to represent the total measured alpha and beta release from the FFTF during standby operation.
Source: BWHC 1999.

from operations at the 400-megawatt power level will bound the normal operational impacts. The standby normal releases are used for both standby and preoperational startup.

The normal operational releases from target irradiation at one or two new accelerators (a low-energy accelerator and a high-energy accelerator) at a generic DOE site used in the analysis of public health impacts are derived from information in Appendix F. The release terms for that accelerator were modified to reflect differences in energy levels to produce the releases provided in **Table H–8**.

Table H–8 Annual Normal Operational Releases from the Low- and High-Energy Accelerators

Accelerator Startup Operations				
	Low-Energy Accelerator		**High-Energy Accelerator**	
Isotope	**Airborne Release (curies per year)**	**Liquid Release (curies per year)**	**Airborne Release (curies per year)**	**Liquid Release (curies per year)**
Nitrogen-13	0.0027	0.33	0.039	4.7
Carbon-14	8.0×10^{-5}	–	0.0011	–
Beryllium-7	2.7×10^{-5}	0.0014	3.9×10^{-4}	0.020
Fluorine-18	–	6.5×10^{-4}	–	0.0096
Argon-41	9.7×10^{-4}	4	0.014	–
Hydrogen-3	3.6×10^{-5}	–	5.1×10^{-4}	–
Accelerator Normal Operations				
Nitrogen-13	0.052	0.33	0.74	4.7
Carbon-14	8.0×10^{-5}	–	0.0011	–
Beryllium-7	2.4×10^{-4}	0.0014	0.0034	0.020
Fluorine-18	1.0×10^{-4}	6.5×10^{-4}	0.0014	0.0096
Argon-41	1	–	22	–
Hydrogen-3	3.6×10^{-5}	–	5.1×10^{-4}	–

The normal operational releases from target irradiation at a new research reactor at a generic DOE site used in the analysis of public health impacts are taken from the analysis in Appendix E. The isotopes and release quantities are provided in **Table H–9**.

Table H–9 Annual Normal Operational Releases from the Research Reactor

Isotope	Quantity Released (curies per year)
Tritium	0.1
Argon-41	2.8

A site has not been selected for either the accelerator(s) or the research reactor. The analysis of public health impacts was performed by assuming a population distribution consisting of a uniform population density of 100 people per square mile within 10 miles of the facility (excluding the area within 2 miles of the facility that was assumed to be within the DOE property) and a density of 200 people per square mile for the area 10 to 50 miles from the facility. Also, a representative "generic" meteorological profile was selected. This weather profile was determined to be representative of the average normal weather conditions for the continental United States. Additional information supporting the selection of this population and weather profile is provided in Appendix I, as the same information has been used for the analyses of both normal operations and accident-related public health impacts.

In the event that DOE selects an alternative that incorporates the use of either the new reactor or the accelerator(s), a specific DOE site would have to be selected for the location of these generic facilities. Selection of a specific site would require additional site- and facility-specific National Environmental Policy Act analysis and documentation, which would address the potential human health impacts associated with operation of the facility at the selected site.

Occupational (Worker) Health Impacts

Health impacts from radiological exposure due to normal facility operation were determined for the facility worker directly involved in the fabrication, irradiation, processing, and storage of the medical isotope and plutonium-238 targets. Health risks to individual workers and to the total workforce were assessed.

The dose to facility workers was derived from recorded occupational exposures at the candidate facilities, or from recorded exposures at facilities that perform similar operations as those being considered in each of the alternatives.

Typically, either the average annual worker dose or the total workforce dose has been provided. The number of workers has been estimated based on prior experience with similar activities at the facility or on activities at similar facilities with the same type of operations.

Table H–10 provides the source data used for the calculation of worker health impacts from radiological exposure associated with normal operations. Additional health impacts (latent cancer fatalities) are derived from these dose parameters, and this information is presented in Chapter 4 for each of the alternatives. Worker doses were converted into the number of projected latent cancer fatalities using the risk estimator of 400 fatal cancers per million person-rem given in the 1990 Recommendation of the International Commission on Radiological Protection (ICRP 1991). This risk estimator, compared with the estimator of 500 fatal cancers per million person-rem for members of the public, reflects the absence of infants and children (the most radiosensitive age groups) from the workforce.

Support facility worker dose estimations are derived from the dose estimates for the operation of RPL at Hanford for the fabrication, processing, and storage of medical isotope targets. The support facility would meet the same DOE requirements and similar administrative requirements for the radiological protection of workers as at existing facilities. Because similar processes would be performed at the support facility as at RPL, it was assumed that radiological and nonradiological worker doses would be similar.

Table H–10 Radiological Impacts on Workers from Normal Operations

Activity	Number of Workers	Average Annual Individual Dose (millirem)	Total Annual Worforce Dose (person-rem)	Source
FFTF in standby	200	3.5[a]	0.69	Nielsen 1999
FFTF preoperational	200	3.5[a]	0.69	Nielsen 1999
FFTF operational	200	6.6[a]	1.3	Nielsen 1999
FFTF deactivation	10	6	0.06[a]	Nielsen 1999
FMEF medical target processing	30	160	4.8[a]	BWHC 1999
FMEF plutonium-238 target processing	75	290[a]	22	LMER 1997
FMEF total target processing	105[b]	250[b]	27[b]	–
Hanford RPL preoperational	40	81	3.2[a]	BWHC 1999
Hanford RPL operations	30	160	4.8[a]	BWHC 1999
ORR REDC	75	290[a]	22	LMER 1997
INEEL FDPF	75	290[a]	22	LMER 1997
INEEL ATR[c]	0	0	0	–
ORR HFIR[c]	0	0	0	–
Generic CLWR[c]	0	0	0	–
Low-energy accelerator operations	100	150	15[a]	Appendix F
High-energy accelerator operations	200	150	30[a]	Appendix F
Research reactor operations	40	100	4[a]	Appendix E
Accelerator and reactor support facility operations	120	102	12[a]	BWHC 1999
Low-energy accelerator decontamination and decommissioning	35	160	5.6[a]	Gallagher 2000
High-energy accelerator decontamination and decommissioning	70	160	11[a]	Gallagher 2000
Research support facility	40	25	1	NRC 1988
Research reactor decontamination and decommissioning	40	275	11	NRC 1988

a. This value is derived from the other two parameters for this facility.
b. These values are the sum of medical isotope target and plutonium target processing at this facility.
c. There are no incremental worker impacts from the use of these currently operating facilities.

H.3 IMPACTS OF EXPOSURES TO HAZARDOUS CHEMICALS ON HUMAN HEALTH

The potential impacts of exposure to hazardous chemicals released to the atmosphere were evaluated for routine operations associated with the alternatives analyzed in this NI PEIS.

The receptors considered in these evaluations are the public. Impacts of exposures to hazardous chemicals for workers directly involved in the treatment process were not quantitatively evaluated because workers use personal protective equipment and engineering process controls which limits their exposure to levels within

applicable Occupational Safety and Health Administration Permissible Exposure Limits or American Conference of Governmental Industrial Hygienists Threshold Limit Values.

As a result of releases from routine operations, receptors are expected to be potentially exposed to concentrations of hazardous chemicals that are below those that could cause acutely toxic health effects. Acutely toxic health effects generally result from short-term exposure to relatively high concentrations of contaminants, such as those that may be encountered during facility accidents. Long-term exposure to relatively lower concentrations of hazardous chemicals can produce adverse chronic health effects that include both carcinogenic and noncarcinogenic effects. The health effect endpoints evaluated in this analysis include excess incidences of latent cancers for carcinogenic chemicals, and a spectrum of chemical-specific noncancer health effects such as headache, membrane irritation, neurotoxicity, immunotoxicity, liver toxicity, kidney toxicity, developmental toxicity, reproductive toxicity, and genetic toxicity for noncarcinogens.

METHODOLOGY

Annual airborne concentrations of hazardous chemicals were estimated from the expected chemical usage provided by the sites and a conservative screening dispersion model described in Chapter 4.

This NI PEIS estimates the noncancer health risks by comparing annual air concentrations of contaminants to the EPA Reference Concentrations published in the Integrated Risk Information System. For each noncarcinogenic chemical, potential health risks are estimated by dividing the estimated airborne concentration by the chemical-specific Reference Concentration value to obtain a noncancer hazard quotient:

$$\text{Noncancer Hazard Quotient} = \text{air concentration}/\text{Reference Concentrations}$$

Reference Concentrations are estimates (with an uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of harmful effects during a lifetime. Hazard Quotients are calculated for each hazardous chemical to which receptors may be exposed. Hazard Quotients for each chemical are summed to generate a Hazard Index. The Hazard Index is an estimate of the total noncancer toxicity potential from exposure to hazardous chemicals. According to EPA risk assessment guidelines, if the Hazard Index value is less than or equal to 1.0, the exposure is unlikely to produce adverse toxic effects. If the Hazard Index exceeds 1.0, adverse noncancer health effects may result from the exposure.

For carcinogenic chemicals, risk is estimated by the following equation:

$$\text{Risk} = \text{CA} \times \text{URF}$$

where:

Risk	=	a unitless probability of cancer incidence
CA	=	contaminant concentration in air (in micrograms per cubic meters)
URF	=	cancer inhalation unit risk factor (in units of cancers per micrograms per cubic meters)

Cancer unit risk factors are used in risk assessments to estimate an upper-bound lifetime probability of an individual developing cancer as a result of exposure to a particular level of a potential carcinogen.

ASSUMPTIONS

The airborne pathway is assumed to be the principal exposure route by which the offsite population maximally exposed individual is exposed to hazardous chemicals released from processing facilities. No synergistic or antagonistic effects are assumed to occur from exposure to the hazardous chemicals. Synergistic effects among released contaminants may result in adverse health effects that are greater than those estimated, whereas antagonistic effects among released chemicals may result in less severe health effects than those estimated.

ANALYSIS

The potential impacts of exposure to hazardous chemicals released to the atmosphere during routine operations of the processing facilities are presented in Chapter 4 for each alternative.

H.4 REFERENCES

Code of Federal Regulations

10 CFR Part 20, "Standards for Protection Against Radiation," U.S. Nuclear Regulatory Commission.

10 CFR Part 835, "Occupational Radiation Protection," U.S. Department of Energy.

40 CFR Part 61, "National Emission Standards for Hazardous Air Pollutants," U.S. Environmental Protection Agency.

40 CFR Part 141, "National Primary Drinking Water Regulations," U.S. Environmental Protection Agency.

40 CFR Part 190, "Environmental Radiation Protection Standards for Nuclear Power Operations," U.S. Environmental Protection Agency.

DOE Orders

DOE Order 5400.5, *Radiation Protection of the Public and the Environment*, January 7, 1993.

Other References

BWHC (B & W Hanford Company), 1999, *Hanford Data Request for FFTF Operational Support Facilities (FMEF Excluded)*, Richland, WA, November 12.

DOC (U.S. Department of Commerce), 1992, *1990 Census of Population and Housing, Summary Tape File 3 on CD-ROM*, U.S. Bureau of the Census, Washington, DC, May.

Gallagher, D.W., 2000, Science Applications International Corporation, Memorandum to NI PEIS Administrative Record, *Distribution of Total Effective Dose Equivalent by Facility Type, 1995–1998*, June 23.

HNUS (Halliburton NUS Corporation), 1996, *Health Risk Data for Storage and Disposition of Weapons-Usable Fissile Materials Final Programmatic Environmental Impact Statement*, Gaithersburg, MD, October.

ICRP (International Commission on Radiological Protection), 1991, *1990 Recommendations of the International Commission on Radiological Protection*, ICRP Publication 60, Pergamon Press, Elmsford, NY.

LMER (Lockheed Martin Energy Research Corporation), 1997, *Comparative Review of Isotope Production Projects and Radiochemical Processing Activities at the Oak Ridge National Laboratory's Melton Valley 7900 Complex (High Flux Isotope Reactor and Radiochemical Engineering Development Center)*, Oak Ridge National Laboratory, Oak Ridge, TN, April 18.

Napier, B.A., R.A. Peloquin, D.L. Strenge, and J.V. Ramsdell, 1988, *GENII--The Hanford Environmental Radiation Dosimetry Software System*, PNL-6584, Pacific Northwest Laboratory, Richland, WA, November.

NAS (National Academy of Sciences), 1990, *Health Effects of Exposure to Low Levels of Ionizing Radiation, BEIR V*, National Academy Press, Washington, DC.

NCRP (National Council on Radiation Protection and Measurements), 1987, *Ionizing Radiation Exposure of the Population of the United States*, NCRP Report No. 93, Pergamon Press, Elmsford, NY, September 1.

Nielsen, D.L., 1999, *Fast Flux Test Facility Data Request in Response to Data Call for Nuclear Infrastructure Programmatic Environmental Impact Statement,* BWHC-9958233, B & W Hanford Company, Richland, WA, December 21.

NRC (U.S. Nuclear Regulatory Commission), 1977, *Regulatory Guide 1.109, Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I,* rev. 1, Office of Standards Development, Washington, DC, October.

NRC (U.S. Nuclear Regulatory Commission), 1988, *Final Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities,* NUREG-0586, Office of Nuclear Regulatory Research, Washington, DC, August.

Wham, R.M., 1999, Oak Ridge National Laboratory, Oak Ridge, TN, personal communication to G. Waldman, Science Applications International Corporation, Germantown, MD, *Radiological Human Health Data,* February 18.